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Laser Research for Military Equipment Technology

Zhang Shengyuan

Abstract

This paper describes the achievements in research and development of laser military equipment technology at North China Research Institute of Photoelectric Technology (NCRIEO) in recent years.

Key words: military lasers

Since the 1960s, the North China Research Institute of Photoelectric Technology (NCRIEO) has been engaged in research military laser technology and equipment, primarily solid-state laser technology and its applications in ranging, tracking, etc., with special interest in range-based laser tracking equipment and laser rangefinders for fire control systems of conventional weapons. The typical features of the range-based laser tracking measurement equipment include high laser pulse repetition frequency, long-distance operation and high measuring accuracy. When installed on a photoelectric tracker or cinetheodolite, this kind of laser ranging device can measure, from a single station, the path of an object in high-speed flight and thus greatly reduce the amount of equipment and raise the accuracy compared with the conventional method of three-station optical cross measurement. Therefore, the application of such equipment is considered as a step forward in developing range-based laser measurement technology.

During the 1970s the weapon testing department advanced, in response to the growing need of intercontinental missile omnidistance test measurement, a research program on laser measurement of the reentry-phase trajectory. It is noted that the nose cone, travelling at a very high speed, will generate friction with the air upon beginning the entry phase, to form dense plasmas called the "Dark Obstacle Zone", which may absorb microwaves and thus cause microwave radar measurement to lose its value. In this case, laser ranging may be adopted as an efficient approach in achieving this key technique.

Research on installing a retro corner reflector on a strategic missile, conducted in 1974, provided the prerequisites for laser measurement of a long-range missile trajectory in its launch phase. That same year was the first time ever that a strategic missile with a corner reflector was successfully tested, based on o YAG pulse laser rangefinder with high repetition frequency as well as artificial semi-automatic tracking. The test proved that the laser was able to operate over distances up to 150 km. Later, the corner reflector was appropriately fitted on the nose cone of a long-range missile. During an omnidistance test of an intercontinental ballistic missile which was completed in 1980, a laser rangefinder installed on a laser cinetheodolite was satisfactorily applied in measuring the nose cone trajectory in the reentry phase. So far, various kinds of laser measurement devices have been developed for test ranges, scattered through the nation. As a result, remarkable achievements were made in areas such as: laser operating range, 600 km; ranging accuracy, 20 cm; and the precision of angle measurement, measured in angular seconds, etc.

In the early 1980s, NCRIEO started a research project on applying the laser rangefinder to conventional weapons, and constructed a laser range and direction finder designed for fire control systems, as well as a laser rangefinder with high

repetition frequency for ship-based air defense and fire control systems. The developed ship-based gun laser rangefinder, installed on a photoelectric tracker, was mainly utilized to measure low-altitude or minimum-altitude targets, with a maximum efficiency of 7 km for sea-skimming missiles and over 20 km for fighter aircraft.

Research on Range-Based Laser Rangefinders

The solid state laser technology developed by NCRIEO laid a foundation for research on range-based laser rangefinders and consequently promoted the development of laser detection technology and other related technologies.

1. High Repetition Frequency Laser Transmitter Technology

To meet the need to accurately measure the orbital parameters of high-speed missiles, special attention was given to the high repetition frequency laser transmitters. In 1968, by using a rotating mirror-dye double-Q switch, a ruby laser was constructed with a repetition frequency of 10 pps and laser pulse power as high as 200 MW and applied in a pulse laser rangefinder with high repetition frequency, the first instrument of its kind in China. Again that year, it was used on the Liaodong Peninsula to measure a corner reflector mounted on a mountain top across the sa, 132 km away. Another high repetition frequency laser, with an Nd:YAG crystal produced in our institute as its laser-oriented working material, was developed in the early 1970s. This double-Q switch laser with a repetition frequency of 20 pps and pulse power of 20 MW laid the groundwork in designing our range-oriented laser rangefinders. In the next several years, various kinds of high repetition frequency YAG pulse lasers, considered advanced by national standards, were build in succession and applied in range-based trackers.

2. Laser Detecting Technique

With the development of laser detectors, photomultiplier tubes (PMT), photodiodes and avalanche photodiodes (APD) were adopted successively as laser detectors. Moreover, different adapter amplifiers and control circuits were made, in compliance with the special features of different detectors, to achieve optimum detection capability. With APD as its receiving system, the detector exhibits a sensitivity of $5 \cdot 10^{-9} \sim 2 \cdot 10^{-8}$ W to 1.06 μm lasers under the sky background as applied in practice.

3. Mounting a Laser Corner Reflector on a Missile

Mounting a laser corner reflector on a missile is a vitally important technique related to the range-based laser measurement system. Essentially, this technique consists of two parts: the first is the mounting technique, which is required in order not to affect the aerodynamic performance and flight attitude of the missile, on the one hand, and to ensure an effective integral value of the reflector within the required limits of orbital measurements on the other; second is design of the heat protection structure which is required to keep the beam angle divergence, due to surface deformation of the corner reflector due to aerodynamic heating, within a desired range.

1) Energy Distribution of Reflected Beam of Corner Reflector

The backward-reflected beam angle of the tetrahedral glass corner reflector is usually designed to be less than 0.1 mrad. the reflected beam angle and energy distribution of the corner reflector are affected by two factors: reflector size and the working error of the 90° angle between its two adjacent reflecting surfaces, and particularly, by surface deformation of the reflector due to aerodynamic heating during high-speed flight. Tests showed these results: (1) During the initial

flight phase, when the surface temperature of the glass reflector installed on the surface of the strategic missile rises from normal atmospheric temperature to 150°, the central energy density of the reflected beam drops moderately; (2) a test of the rise in surface temperature of the corner reflector mounted on the outer side of the nose cone reveals that this temperature rise in the reentry flight phase may reach 1000~1250° C; and (3) the surface temperature rise of the quartz glass corner reflector and the reflected beam central energy variation as tested are shown in Table 1. It is believed then, by analyzing the test results, that in the reentry flight phase, the missile can still perform laser ranging within dozens of kilometers, even if the central energy of the reflected beam is drastically reduced.

Table 1. Analog Test Results of Reentry-Phase High Temperatures

Temperature rise of the heated surface	(°C/30 s)	200	400	600	700	900	1000
Relative change of central energy	(%)	80	45	25	15	8	3

2) Mount Structure of Missile Corner Reflector

In the process of designing the structure of the corner reflector, a series of structure tests were conducted, including a survey test of the surface contamination of the reflector during missile launch; a flight test of the protective cover structure of the reflector; a test of surface contamination of the reflector by combustion products generated in the reentry phase, and a test of the aerodynamic effects of the reflector mount structure on missile flight. Based on these tests, the mount structure of corner reflectors on different missiles was successfully designed.

4. Ranging Precision

Improvements in the ranging precision, one of the major purposes of lasers applied to range measurements, was seen as a key technique for study. In the mid-seventies, research on 1 m precision laser ranging was undertaken. The measurements of the first laser rangefinder with meter level precision are listed in Table 2.

Table 2. Measurements of Ranging Precision

标点编号 1	标准距离 2 (m)	测量平均值 3 (m)	随机误差 δ 4 (m)
A_1	1474.658	1474.35	0.76
A_2	13760.017	13760.33	0.85
A_3	33356.347	33356.44	0.60
A_4	62703.987	62703.82	0.82

Key: 1. Number of marks; 1. Standard distance;
3. Average value measured; 4. Random error

Later in the mid-eighties, a decimeter-level rangefinder installed on a microwave radar was invented. This device ensures a precision of 0.2~0.3 m for missile tracking and a measurement of fixed-point ranging accuracy of less than 10 cm for the corner reflector.

5. Systematic Tests on Range-based Laser Measurement System

Prior to the range-based laser measurement of missile trajectory, a variety of tests were implemented, such as a test of the laser capability in penetrating the exhaust plume, a test of surface contamination of the corner reflector by combustion products from the engine while the missile is being launched, and a test on the ranging capability of a ground-based long-distance corner reflector. As a result, large amounts of data were obtained, which provided the measurement with a reliable basis.

Dozens of systematic tests on the performance of the range-based measurement devices as listed were all carried out on different weapon test ranges around the country, including islands, ships, the Gobi Desert or remote mountainous regions, where the test crew had to endure very harsh conditions at both work and daily life. Table 3 lists some typical test results with maximum probability of laser detection as high as 98.2%.

Table 3. Rest Results of Range-based Laser Measurements

时间 1	测量段 2	功率 3 (MW)	4 接收口径 (mm)	5 角反射面积 (cm)	探测器 6	跟踪架 7	8 测量距离 (km)
1974	9 初始段	10	200	40	PMY	10 转台	3~150
1977	9 初始段	20	150	54	PMT	经纬仪 11	~203
12 1980	再入段	30	370	≥40	PMT	经纬仪	77~ 11
1982	9 初始段	20	150	60	PMT	11 经纬仪	30~320
1988	9 初始段	20	150	40	APD	13 雷达	70~600

Key: 1. Time; 2. Measurement phase; 3. Power; 4. Receiving caliber; 5. Corner reflecting surfaces; 6. Detector; 7. Tracking stand; 8. Measuring distance; 9. Initial phase; 10. Rotary table; 11. Theodolite; 12. Reentry phase; 13. Radar

As far as the range-based laser measurement equipment made in foreign countries is concerned, its ranging capability is known to be 60 km, performed by an aircraft with a corner reflector.

The error sources affecting the precision of laser tracking includes noises coming from the atmospheric jet stream, target light spottiness, backscattering and laser light spots, in addition to sources from laser ranging. As for the angular error caused by electrical circuits, it can be reduced through real-

time computer correction. To enhance the precision of trajectory measurement, the following techniques are applied in the range-based measurement devices developed by our institute: (1) single mode lasers with a repetition frequency 40~100 pps, which can reduce fluctuations in density distribution of target-irradiating light spots and therefore reduce the angular error derived from uneven light spots. With higher sampling frequency, the tracking precision of the system was improved; (2) optical automatic gain control, which can confine the energy of the backward wave entering the detector within an optimum range of values; (3) computer correction of the angular error caused by the shape of imaging light spots; and (4) range-gatings which can greatly decrease the angular error caused by backscattering.

The laser tracker installed on the photoelectric theodolite, the first one designed by our institute, provides an angular precision of 7 angular seconds as a design value, and 5 angular seconds as a laboratory computed value.

Fire-control Laser Ranging Technology

Presently, laser range finders have been used in many countries to equip various army units as an important element of present-day weaponry; in particular, it fully demonstrates superiority when applied as a ship-borne anti-missile system. In the ship-borne gun system, the photoelectric fire control system with the function of laser ranging can overcome the difficulties that microwave radar may encounter while measuring low-altitude targets. Laser ranging can resist not only the interference from microwaves, but also interference from sea waves that affect the light wave reflection. Laser measurement of targets is hardly restricted by any elevation angle. Therefore it is the most efficient means so far for measuring the attacking minimum altitude (sea-skimming) missiles in counterattack.

The fire control laser rangefinder developed by our institute includes a high-sensitivity APD detector and also, an optimum APD gain working voltage for comprehensive control of noise and temperature, for an optimum signal-noise ratio under various backgrounds and working environments.

The author, Zhong Shengyuan, a senior engineer born in December 1937, graduated from the Xi'an Telecommunication Engineering Institute in February, 1964. Upon graduation, he has engaged in research of military laser technologies and equipment and won a number of scientific achievement awards at the national and ministerial levels for engineering projects completed under his direction.

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